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COOPERATIVE LASER RANGING RESEARCH PROGRAM

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A lunar laser ranging facility was established at Orroral Valley, Australia by the Australian Division of National Mapping with the assistance of the Smithsonian Astrophysical Observatory with equipment obtained from the Air Force Geophysics Laboratory. Range measurements to lunar reflectors are made from this facility regularly. Some equipment problems must still be overcome before this observatory becomes fully operational.

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COOPERATIVE LASER RANGING RESEARCH PROGRAM

FINAL REPORT

Contract No. F19628-73-C-0089

1. INTRODUCTION

Under this contract, the Smithsonian Astrophysical Observatory (SAO) assisted the Australian Division of National Mapping (NATMAP) in the establishment and operation of a laser facility for ranging to distant orbiting and lunar targets. A lunar laser ranging (LLR) system was obtained from the Air Force Geophysics Laboratory (AFGL) and installed at Orroral Valley, Australia, under the direction of Dr. Peter Morgan, Senior Surveyor, NATMAP. Modifications were made to the equipment to enhance its capability to range to lunar reflectors and distant satellites and to obtain data for geodetic and geophysical research. Lunar ranging has been underway since late 1976 with some apparent success. A regular schedule of measurements to lunar reflectors has been established, although several problems must be overcome before the system is operational. No definitive statement of returns can be made; however, some promising patterns have emerged. The equipment, which had been obtained under Contract No. F19628-73-C-0089 with AFGL, was transferred to the Smithsonian Institution on 6 December 1976.

2. THE LUNAR LASER RANGING FACILITY

2.1 Establishment of the Facility

2.1.1 Basis of cooperation

The cooperative laser ranging research program began in 1972 when the AFGL closed its laser ranging facility at Mt. Lemmon, near Tucson, Arizona. Discussions among AFGL, the National Aeronautics and Space Administration (NASA), SAO, and NATMAP were held to explore the feasibility of using this equipment to establish and operate a laser facility in Australia to range to distant orbiting and lunar targets to gather data for geodetic and geophysical research.

In early 1973, discussions resulted in a series of cooperative agreements for the acquisition and operation of the equipment — notably among AFGL and SAO, SAO and NASA, and SAO and NATMAP.* The LLR system was obtained by SAO from AFGL in November 1972 as government-furnished equipment under AF ESD Contract No. F19628-73-C-0089 to perform cooperative laser ranging research; the system was dismantled and shipped to Australia, where it arrived in March 1973.

2.1.2 Site selection

While these negotiations were in progress, NATMAP evaluated a number of local Canberra sites for suitability and logistics feasibility. Among the sites investigated were Mt. Stromlo Observatory, Mt. McDonald, the Orroral Valley collimation tower area, the Honeysuckle Creek collimation tower area, and Kowen Forest. The Orroral Valley collimation tower area, part of the NASA Satellite Tracking and Data Acquisition Network (STADAN) facility at Orroral Valley, was selected. Its

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* To facilitate the establishment of a suitable observatory, SAO received NASA Grant NGR 09-015-208 for $24,995 for support of the lunar laser ranging system in Australia. This grant was effective 1 January 1973 and terminated 30 September 1976.

meteorological characteristics are neither more nor less favorable for optical work than those at Mt. Stromlo, but it offers the following advantages:

A. The possibility of building a complex astrogeodetic site.

B. Dark skies and better optical extinction.

C. Freedom from city light pollution.

D. Support for logistical services.

After investigating the area's geology and the possibility of electromagnetic radiation interfering with the STADAN facility, conducting further seeing tests, and completing an environmental impact statement, site selection was made in May 1973. Final approval was received that September, and work on clearing the site and preparing the foundation area commenced immediately.

2.1.3 Site construction

Figure 1 gives a general view of the site and building; geodetic survey pillars* are visible on each side of the building.

Work on drilling and blasting the foundation rock continued throughout October 1973; in the following month, bids were let for building construction and an order was placed for the Ash dome.

Blasting and preparations of the building area were completed in February 1974, at which time a contract for the erection of the LLR system was let with a specified completion date of early June.

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* To complement the laser activity and provide sufficient data to separate local crustal movement from general tectonic movement, a first-order geodimeter network was established; it is centered on Orroral Valley and extends over 40 km in all directions. Simultaneously, a first-order leveling survey over 250 km was completed for vertical-movement studies. It is hoped that these measurements will be repeated in late 1977 to gain some idea regarding the local strain pattern in the area. The survey has also interconnected, to the highest possible precision, the SAO laser facility in Orroral Valley, the Jet Propulsion Laboratory's Deep Space Net antennas at Honeysuckle Creek and Tidbinbilla, and the classical PZT at Mt. Stromlo.

Figure 1. General view of the Orroral Valley LLR building and site; geodetic survey pillars can be seen on either side of the building.

In July 1974, the telescope, which had been undergoing testing at the Australian National University, was dismantled and packed for transfer to Orroral Valley. The main frame was placed in position late in the month, and the Ash dome was immediately installed to waterproof the building. From August through November, efforts were concentrated on providing the new building with services; occupancy was achieved late that November.

2.1.4 Equipment installation

Equipment reassembly and installation proceeded insofar as possible throughout the period of construction. Reassembly of system components commenced in the spring of 1973 and continued in phases; use was made of the facilities of the Orroral Valley STADAN station, where the laser was reassembled and test-fired, and the workshops of the School of Earth Sciences of the Australian National University, where the telescope, minus the primary and secondary mirrors, was refurbished and test-assembled.

Near the end of October 1974, specifications for the minicomputer to control the system were made final, and progress continued in assembling the laser and electronics; this work benefited from a visit of Mr. J. D. Williams, who was previously in charge of the equipment at Mt. Lemmon. Work temporarily ceased on this part of the system when the STADAN station was no longer able to provide work facilities. The laser and electronics were disassembled and packed for storage.

Reassembly of the telescope in the workshops at the Australian National University continued until 1 July 1974, when its main frame was installed in the newly constructed LLR building.

In 1975, the 60-inch telescope was refurbished and all stored equipment was sent to Orroral Valley. Installation of the telescope took much longer than anticipated because of unexpected difficulties with the gears and drive assemblies. Problems in handling large and heavy items in and around the telescope were also experienced. The primary mirror was installed in May 1975.

General system development work, including cabling, system control, and computer interaction, together with problems of telescope alignment, dominated the remainder of 1976.

Early in February 1976, the telescope was brought into final alignment both internally and relative to the refracted pole; good images resulted. The laser was then mounted on the telescope and fired successfully. Work continued on both the laser transmitter and the receiver segments, with the latter finally reaching the telescope by May.

A number of problems appeared during regular test firing of the laser, and considerable effort was expended in modifications. The first attempts to acquire the target with the refurbished system took place in July 1976. The LLR has been operated on a scheduled basis since mid-1976 with some apparent success. Attention is still being given to a number of operational and hardware problems.

Figure 2 shows a general view of the observing floor, wherein the main north pier and the guidance rack for pointing are seen. The lightweight mirror design is readily visible.

2.2 SAO Activities

Throughout this period, SAO acted as the principal United States interface among the various cooperating agencies and provided NATMAP with advice, recommendations, and coordination services in such areas as site development, systems engineering, and overall facilities integration.

SAO procured and sent to NATMAP various items and pieces of hardware not available in Australia and provided continual logistics support.

SAO was particularly active during periods of initial reassembly and testing of the laser and electronics and during computer installation and telescope alignment. NATMAP relied on the supply channels of SAO for electronics and laser supplies, as American standards were maintained on the equipment.

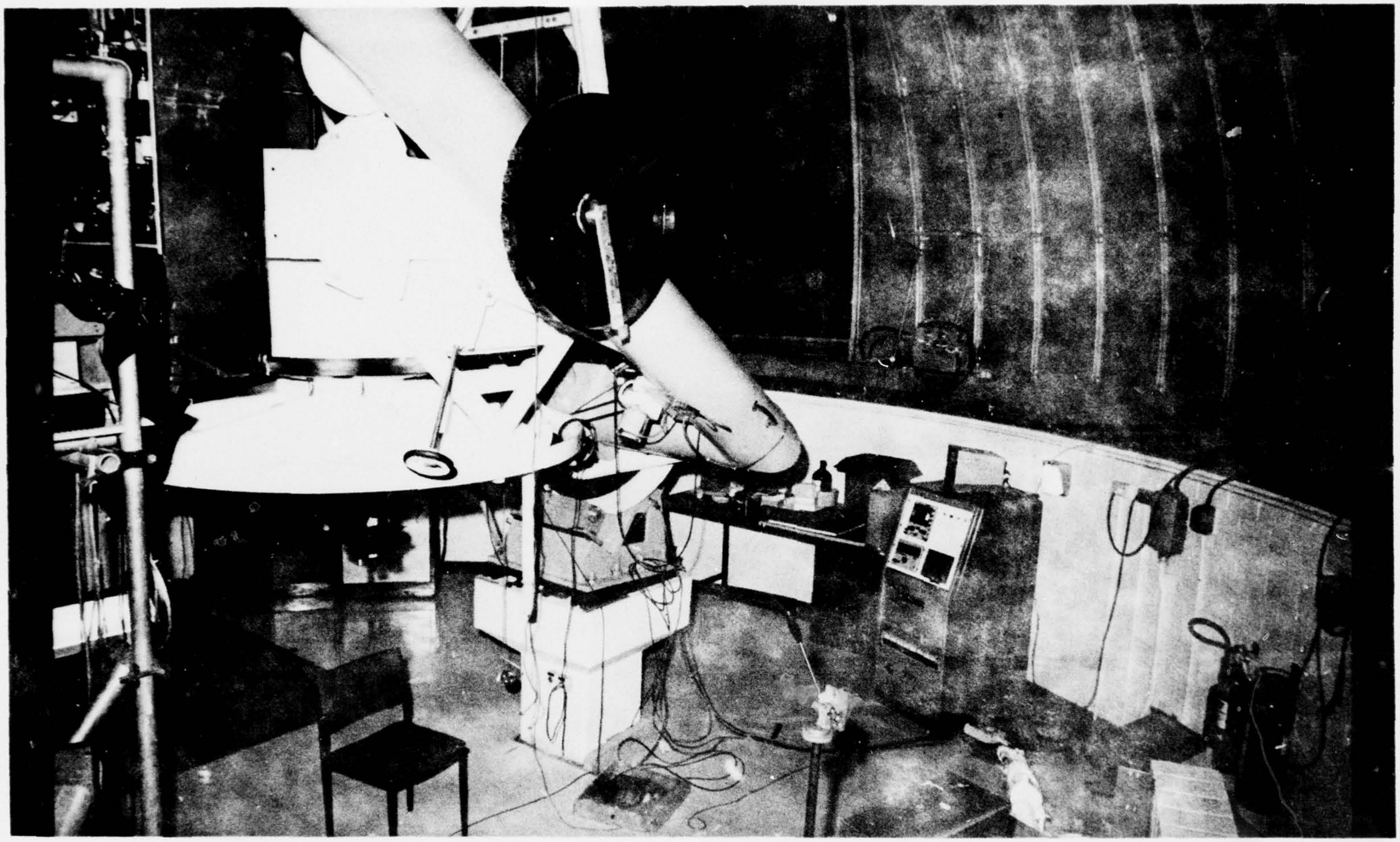

Figure 2. General view of the observing floor of the LLR facility.

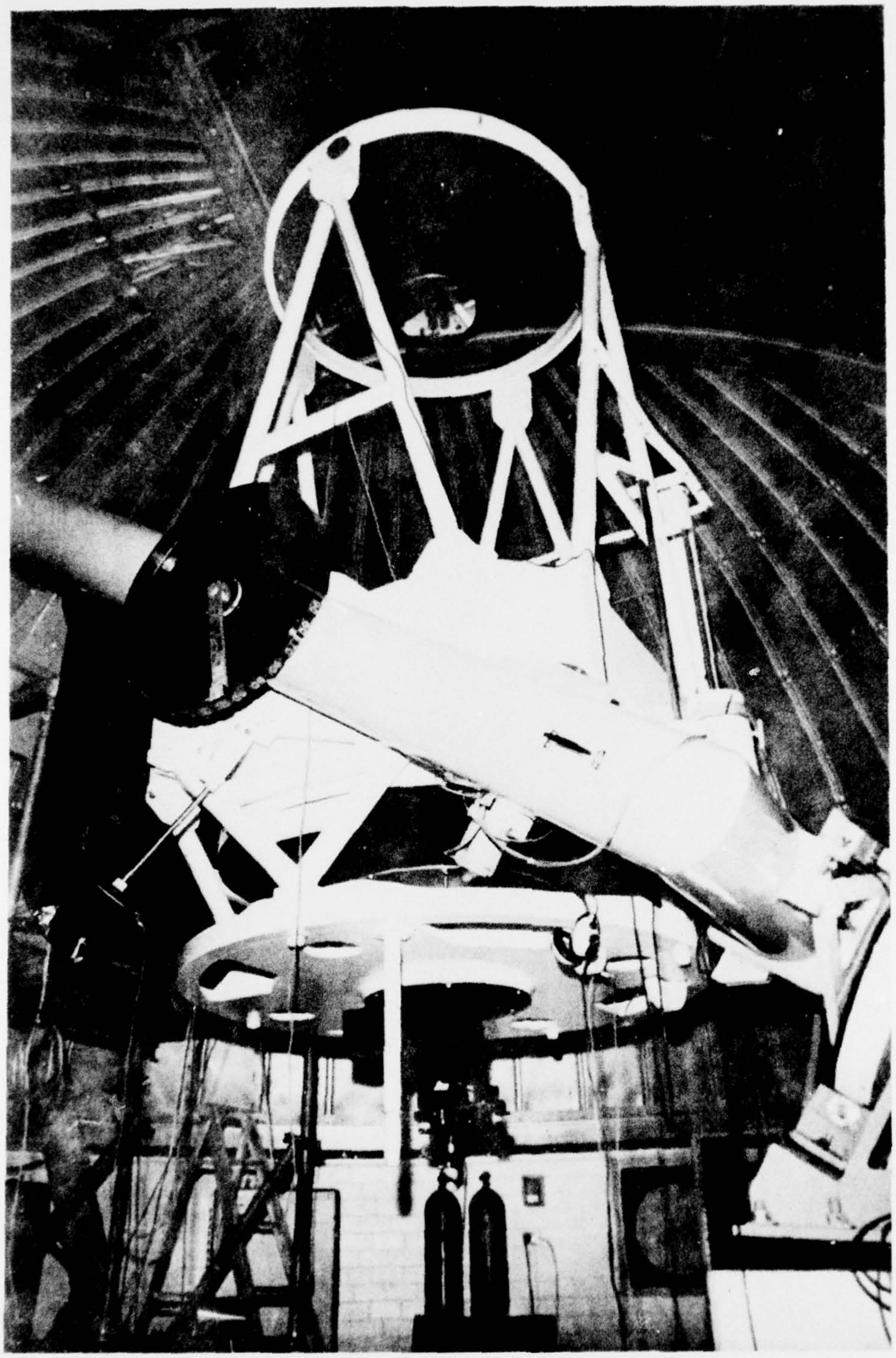

Figure 3. General view of the 60-inch reflecting telescope at the LLR installation.

SAO will continue to maintain a close relationship with NATMAP when the LLR becomes fully operational and will remain interested in field observational activities, including equipment modification and maintenance, parts procurement and transportation and other logistic and administrative matters.

3. THE LLR SYSTEM

The original shipment of equipment from the United States consisted of the following subsystems: a 60-inch English-yoke-mounted telescope, a ruby laser, the timing circuit and electronics, and a command module. This equipment was originally obtained by SAO from AFGL as government-furnished equipment under Contract No. F19628-73-0089; accountability for the system was transferred to Smithsonian Institution as a Government agency on 6 December 1976.

Several modifications were made to system components to enhance its operational capability; these are discussed separately below.

3.1 The Telescope

The 60-inch reflecting astronomical telescope was installed in a classical manner. Adjustments for latitude variation between Mt. Lemmon and Orroral Valley were done with shims. Adjustments to the inclination of the yoke necessitated changing the location of the 6-inch refracting telescope, used as a finder on the system, to a place high on the trusses. Although this alteration did not limit the declination range of the telescope, it prevented the eyepiece from being used. A standard vidicon camera system was therefore fitted to the telescope. Experience with this system shows that fifth-magnitude stars can be detected for general system work. However, the greatest gain is in the quality of the lunar image, which generally has better contrast than the standard main field optical train and reduces the time spent searching for lunar-target areas and guide craters.

The tracker unit of the telescope required considerable modification to provide it with the reverse-drive capability necessary for the Southern Hemisphere. At the moment, both the polar axis and the declination axis are variable to a few parts in 50,000 of the period of a standard pulse (50 msec). This modification – with its update capacity, which enables the basic rate of the telescope to be matched to the lunar rate and not to the sidereal rate – has improved tracking and reduced the dependence on the supplied feedback loop generated via the image dissector tube. This latter facility is not yet fully converted.

A general view of the 60 inch telescope is reproduced in Figure 3.

3.2 The Ruby Laser Transmitter

It has been difficult to maintain the laser in an operational state. Although the current configuration is similar to the original one at Mt. Lemmon, many concepts have been changed. Some of the more important differences are as follows:

A. The basic method of Q-switching the cavity has been changed from a rotating prism to a saturable dye. This will shortly be converted to a Pockels cell in order to improve stability and eliminate the alignment modifications that are currently necessary when the dye cell is removed for refilling.

B. Many optical components have been relocated within the laser box, which was found to be susceptible to flexure induced by different telescope aspects.

C. The laser fire control was redesigned and rebuilt by using integrated circuits and computer control logic rather than fixed digital logic.

As of the date of this report, the laser still has reliability problems. It needs constant adjustment to maintain the required pulse characteristics of better than 1 joule into the telescope with a half-power pulse width of 15 nsec. A number of upgradings are being carried out; among these are the transformation of the present dye-cell oscillator cavity into a Pockels-cell-switched cavity and the lengthening of the laser oscillator. Computations indicate that a pulse width of 20 nsec should be obtainable with power levels at 40 Mw using a Pockels cell for the Q-switch. Lengthening the oscillator will make alignment simpler, will reduce the mode structure, and will increase the efficiency of the pulse.

Figure 4 shows the lunar box attached to the declination cube of the telescope.

3.3 Timing Circuits and Electronics

The timing and electronics circuits have been modified extensively to accept the application of computer control instead of hard-wired control, much of which was DTL technology.

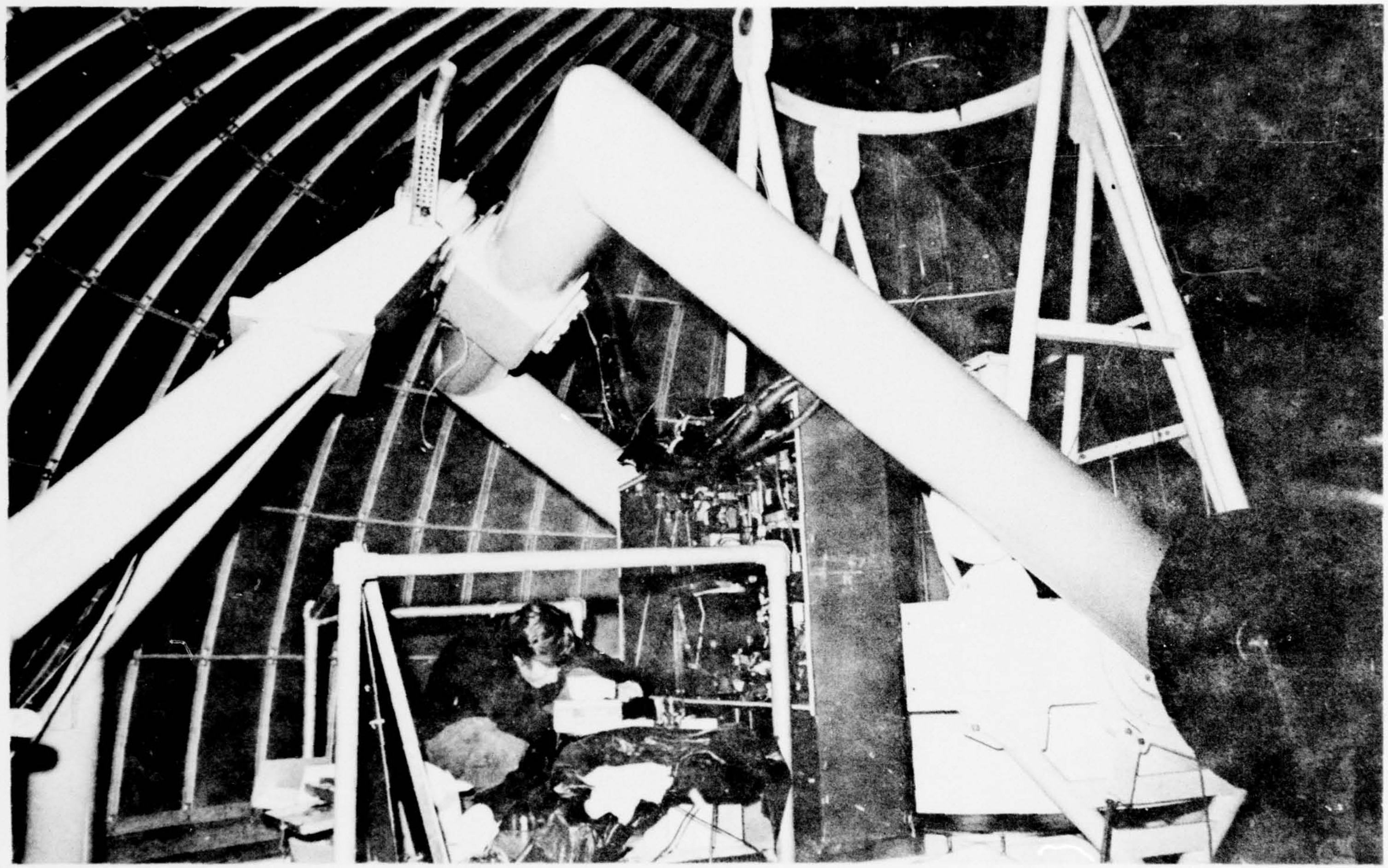

Figure 4. The laser box attached to the declination cube of the telescope.

In adapting the system to computer control, the time-interval counter was interfaced to the minicomputer, where a series of messages identifying various phases of the ranging process originates; this has allowed use of the same counter channel for both start and stop pulses. The photomultiplier-tube electronics and the amplifier were also modified for computer control, the principal changes being the incorporation of facilities for applying the high voltage just before the opening of the window and the insertion of a variable window about the expected return.

3.4 The Command Module (Computer System)

The hard-wired command module has been fully replaced by the Hewlett-Packard 21MX minicomputer and associated software. The minicomputer enables the system to be controlled dynamically with a far greater range than normally achieved with hard-wired logic. In addition, the electronics in the command module could no longer be readily supported because of changes in the electronics industry. Figure 5 gives a view of the Hewlett Packard 21MX computer and timing electronics.

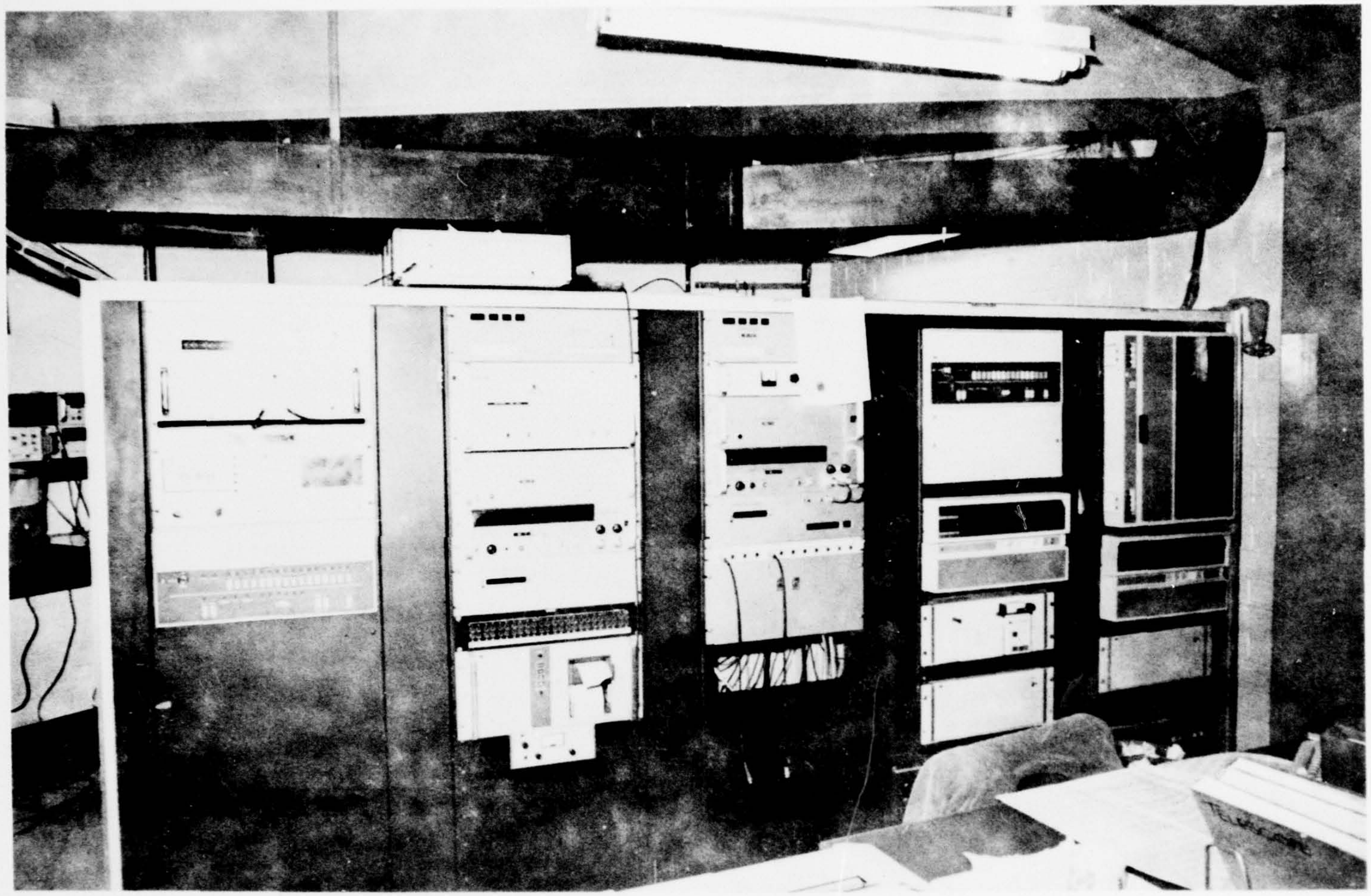

Figure 5. View of the Hewlett Packard 21MX computer and timing electronics, LLR facility.

4. OPERATIONS

4.1 Ranging Progress

The first ranging attempts were made in July 1976. Further attempts have taken place during all lunations since then, with a gradual buildup in system reliability. Although there have been numerous failures in the system — principally in the laser area — each passing lunation brings more nights spent tracking and fewer spent building and refurbishing the system.

A regular operating schedule has been established, and an operational summary is issued routinely, a recent example of which is attached as Appendix A.

To date, the ranging, with one exception, has been limited to that period of the moon where its phase is greater than 0.20 and less than 0.80. This limitation has provided not only the best part of the moon for ranging but also a suitable amount of time between lunations to enable modifications and improvements to be made on the system. When the system produces identifiable ranges, this limitation will be eliminated.

Arrangements have been successfully established for transmitting data from Australia to the United States. Transfer is done via computer to the University of Texas at Austin, where filtering and other testing are performed. Verified range data will be available from both the University of Texas and NATMAP.

As yet, no definitive statement of returns can be made, although some promising patterns have emerged.

4.2 Contributing Scientists, Engineers and Support Staff

In addition to the Contract Monitor, Dr. Donald Eckhardt of the Terrestrial Sciences Division, AFGL, the following scientists and engineers have made signi-

ficant contributions to the cooperative laser ranging research program. Administrative and logistics support required for the performance of the contract was provided by those listed below and others at NATMAP, NASA, and several universities in the Orroral Valley area.

4.2.1 Scientists

Dr. Peter Morgan	NATMAP
Dr. Michael R. Pearlman	SAO
Dr. Eric Silverberg	McDonald Observatory, University of Texas

4.2.2 Engineers

Mr. Colin Cochran	NATMAP
Mr. Noel Lanham	SAO
Mr. J. D. Williams	University of Hawaii
Mr. Jakob Wohn	SAO

4.2.3 Support staff (administrative and logistics)

Ms. Margaret Bush	SAO
Mr. Preston R. Clark	SAO

5. FUTURE PROGRAM

Dr. Michael R. Pearlman, SAO Principal Investigator for the cooperative LLR program, visited the Orroral Valley site in February 1977; he inspected the facility and held operational and technical discussions with Dr. Morgan.

The system is operating, although some problems remain concerning the reliability of the laser transmitter and the susceptibility of the 60-inch telescope photoreceiver to noise, particularly when ranging on the illuminated moon. Redesign considerations are under review to increase system reliability, to put the optics in a more stable configuration, and to enable the system to operate in the short-pulse mode. Possible solutions of the telescope problem center on the installation of a narrow-band filter to reduce the noise level. Currently, the telescope optics are being cleaned and realuminized at Siding Springs, Australia, in preparation for a future lunar tracking campaign.

General discussions have also been held to consider adapting the LLR system for ranging to the Lageos satellite; this would entail modifying the declination drive of the telescope to give a larger continuous adjustment. This project is under consideration for the 1978 or 1979 time frame.

It is expected that system development will advance, increased reliability will be achieved, and future program plans will evolve as the cooperating agencies continue to pursue their research objectives using the techniques of laser ranging to distant orbiting and lunar targets for furthering geodetic and geophysical knowledge.

SAO will maintain an active interest in the program and will continue to act as the principal United States interface among the cooperating agencies in the operation and maintenance of the facility.

APPENDIX A

LLR FACILITY, ORRORAL VALLEY, AUSTRALIA

OPERATIONAL SUMMARY

February 4-18, 1977

	PZT Plates	Timation Passes	Moon Phase	Ranging	
Friday 4.2.77	0	2	1.0	Nil	no scheduled shift
Saturday 5.2.77	0	2	1.0	Nil	no scheduled shift
Sunday 6.2.77	0	1	0.97	Nil	no scheduled shift
Monday 7.2.77	0	2	0.93	Nil	no scheduled shift
Tuesday 8.2.77	0	1	0.85	Nil	shift changed to take out mirror
Wednesday 9.2.77	0	0	0.76	Nil	
Thursday 10.2.77	0	1	0.66	Nil	
Friday 11.2.77	0	1	0.54	Nil	mirror taken out of telescope
Saturday 12.2.77	0	1	0.42	Nil	
Sunday 13.2.77	0	0	0.31	Nil	
Monday 14.2.77	0	2	0.21	Nil	
Tuesday 15.2.77	0	1	0.12	Nil	
Wednesday 16.2.77	0	1	0.06	Nil	
Thursday 18.2.77	0	0	0.02	Nil	